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LECTURES

ON

PHYSIOLOGY.

BAYLORD BROS.

TEXT OF LECTURES

ON

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ANALYSIS.

Preliminary Definitions and Distinctions.

Physiology, Anatomy, Morphology, Hygiene.

Living bodies: *Animal* bodies.

Classification of the Functions.

I. **Mechanical Functions,** and their apparatus.

1. The *skeleton,*—external or internal.
   The human skeleton described,—bones of trunk, head, limbs.
   Comparative anatomy of the skeleton.

2. *Muscle;* its structure and mode of action.
   Certain muscles of the human body described.
   Muscular anatomy in relation to external form and art.
   Animal mechanism,—the erect posture, walking, &c.
   Effects of muscular exercise.

II. **Nutritive Functions.**

1. Food and Digestion.
2. Absorption.
3. Formation, properties and Circulation of Blood.
4. Respiration.

5. Assimilation.
6. Secretion.
7. Animal Heat.

III. The **Nervous System,** and its functions.

1. Its general uses and constituent parts.
2. Spinal cord, and Medulla oblongata.
3. Brain.
4. Sympathetic system.
5. Hygiene of the nervous system.
6. Sensation, and the special senses.

IV. **Reproduction and Development.**

PHYSIOLOGY.

Physiology is a study of the functions of living bodies.

Anatomy is a study of the organs,—their form, structure, position, and sensible properties.

Morphology adds to descriptive anatomy, a study of the development of organs, and their correspondences in essential nature, as distinguished from functional use.

Anatomy views the organs as at rest; physiology, as in action. Physiology presupposes Anatomy; or, in a large sense, includes it.

Morphology views the organs in relation to their place in the scheme of nature; physiology, in relation to their use in the individual being.

Anatomy consists of *description;* physiology contemplates *use;* morphology deals with *plan.*

Hygiene is a study of the conditions and laws of Health.

Anatomy or Physiology may be animal or vegetable; human or comparative. In this course, we make the human being our special object of study. But we cannot understand the physical life of man without considering that of other animals.

DISTINCTIONS OF LIVING BODIES.

1. A living body maintains its structure by continued interchange of elements with the surrounding world. Its molecules change, while its form remains the same, or grows by a law inherent in itself. Hence the need of food. The change is most rapid where functions are most active.

2. Living bodies can propagate their species. The race survives, while individuals die; as the body survives, while its particles die.

3. Their form is somewhat definite, and bounded rather by curved than straight lines and surfaces.

4. Their chemical composition is complex and unstable.

5. They grow by internal assimilation instead of external accretion.

6. Most living bodies are organized; *i. e.*, they present dissimilar parts (organs) definitely related to one another.

Protoplasm, a structureless compound of C, H, O, N, having powers of movement, assimilation and reproduction, is regarded as the physical basis of life. The simplest organized form is a cavity, with a wall distinguishable from its contents, called a *cell*. It usually contains a nucleus and soft or liquid protoplasm.

Living bodies present every degree of complexity from structureless masses upward. As life becomes more elevated and varied, distinct organs appear, assigned to special uses. The tissues of the highest animals are regarded as modified protoplasm, with one or another property specially developed.

DISTINCTIONS OF ANIMAL FROM VEGETABLE BODIES.

The higher animals are distinguished from vegetables by the powers of sensation and voluntary movement. In the lower forms, no distinction holds absolutely good in all cases.

1. Plants convert inorganic substances into protoplasm, thus furnishing the physical basis for higher living forms. Animals require protoplasm to be formed for them. Plants organize; animals consume.

2. In doing this, plants give off O; they are deoxidising agents. They do this under the influence of sunlight. Animals take up O; they are oxidising agents; and by this oxidation, or burning, they develop power.

3. Animals are generally locomotive; they travel for food. Plants, generally stationary, grow toward their food.

4. Animals have an internal digestive cavity; plants generally do not.

The *functions* of the animal, or human, body may be *classified* in various ways.

1. Food must be taken into the system, and prepared to nourish its organs. As much food is solid, it must be reduced to solution or finely sub-divided, and then absorbed into the body. A fluid, poured through all parts of the body, brings supplies of nutriment, and takes away the products of interstitial waste. This fluid is the Blood. Remarkable mechanisms are needed to keep it in constant and rapid flow. It must be contin-

ually rid of impurities, resulting either from the necessary waste of tissues, or from wrong or excessive food. Oxygen must be steadily supplied. The several tissues must have the power of feeding themselves by assimilating proper elements from the blood. These functions require the fluidity and temperature of the solids and liquids to be kept within certain limits; water and heat must therefore be supplied and regulated.

The functions thus indicated, needful for the maintenance of the body, are called *nutritive* or *organic* functions.

2. But, in proportion to physiological division of labor, or as distinct organs are set apart for different functions, some means of communication between these organs is required, to harmonize their actions. This is furnished by the nervous system. For the higher offices of life, consciousness, sensation and voluntary movements, the nervous system brings body into relation with mind.

This class of functions is called the *nervous*, or the functions of *relation*, or of *animal* life.

3. Lastly, a third division includes the functions of Reproduction and Development, by which new organisms are produced.

This classification of the functions is the most logical, though the distinction is not absolute. A more convenient arrangement is to begin with those functions which involve only common, mechanical forces, such as are found also in bodies without life, and pass to those which require more peculiar modifications of force, such as act in living bodies only. This principle governs our order of study in this course.

We shall consider:

I. Mechanical Functions, and their apparatus.

II. Nutritive Functions, which involve physical and chemical, as well as mechanical forces.

III. The Nervous System, and its functions; which require so-called nervous force.

IV. Reproduction and Development.

I. Mechanical Functions, and their Apparatus.

THE SKELETON.

The skeleton upholds and shields vital organs, determines the general shape, and is the *passive* instrument of movement. It may be external or internal (*exo-* or *endo-skeleton*).

The Exo-skeleton is more developed in the lower divisions of the Animal Kingdom. It is formed of the skin, more or less hardened. The spiny hide of the star-fish, prickly with calcareous particles, may be regarded as an exo-skeleton.

Shell-fish represent the *Mollusca,* so named from the softness of their bodies. The body is enclosed in a somewhat tough skin, on the outside of which this shell is formed, consisting of compounds of lime, especially the carbonate. It protects the vital organs, and aids passively in their generally limited movements. Some shells are chambered, representing the successive growth and dwelling-places of the animal.

The Exo-skeleton is best represented in the most extensive division of the Animal Kingdom, known as *Annulosa* (or *Articulata*). These comprise worms, insects, centipedes, crustacea. Their skin is hardened in various degrees. It is divided into transverse segments (rings or joints; whence the names). All the higher Annulosa (hence named *Arthropoda*) have segmented limbs,—not less than six. To these gliding segments, muscles are attached, lying inside of the skeleton, and moving it. The active organs of motion are inside of the passive. Many Annulosa have great powers of movement, keen and varied senses, and very highly developed instincts. They form the most numerous branch of the Animal Kingdom; both in species and in individuals. Insects are specially interesting, from their vast numbers and consequent powers of good and harm, from their transformations, and the great development of the powers of *animal* life.

The back-boned animals (*Vertebrata*) form the highest branch of the Animal Kingdom. In them the exo-skeleton is generally slightly developed, being represented by the scales or bony plates of many fishes, the shield of the turtle and armadillo, our own finger-nails, &c. The *endo-skeleton*, appearing but little in other animals, becomes highly developed in Vertebrata.

It consists in early life mainly of cartilage or gristle, a tough elastic substance, containing few or no blood-vessels. In the higher races, as they grow up, this changes to bone. The change consists in its becoming channelled by blood-vessels, and hardened by compounds of lime. The vessels form minute canals through the substance of bone (Haversian canals); and the bony matter is formed in concentric layers around these. As bone is thus vascular, it is red and moist in its interior,

during life; and is subject to the same laws of nutrition as other tissues; bones are repaired when injured, absorbed when no longer needed. The mineral constituents of bone make two-thirds of its weight, chiefly calcium-phosphate. Hence this is a necessary ingredient in food, and in soils. Deficiency in mineral compounds makes the bones soft. Animal matter gives them toughness and elasticity. The bones of children are more elastic; those of the old, more brittle.

Flat bones (as of the skull-cap) are developed between two layers of membrane, from certain centres of ossification. The long bones of our limbs consist of shaft and extremities, developed from distinct points of ossification. The smaller parts of a bone, developed from separate centres, and afterward becoming attached to the main bone, are called *epiphyses*. When mature, the shaft presents compact walls with a central cavity; the extremities consist of cancellated structure, or thin walls of bone with numerous irregular spaces. These cavities contain a yellowish or reddish fat called marrow. Some bones contain air instead.

Bone is covered by a close-clinging membrane, *periosteum*, which supports the blood-vessels, and give attachment to muscles.

A *process* is a projection of bone.

Plan of the Vertebrate Endo-skeleton.

The essential part of the Endo-skeleton is a column, running along the back, firm enough to keep the body in shape, yet more or less flexible to permit movement. It consists of a series of rings, like a string of beads. Being placed in a row, the openings through these rings make a long canal. The rings are called vertebræ.

The column is vertebral or spinal column, spine, or back-bone. Its canal contains one great central portion of the nervous system (spinal cord). Nerves go off through openings between its rings. At its forward end, the spine dilates into the cranium, to hold the brain.

Animals thus formed are named *Vertebrata.* Their body is segmented, as is that of Annulosa. But this segmentation is less obvious, being internal. They differ from invertebrated animals in having the body-cavity divided into two,—the upper or *neural* cavity containing the nerve-centres,—the lower (*hæmal*) containing the chief nutritive organs. To form these two, the body or centrum of the vertebra sends off a neural arch upward; and in a complete segment of the skeleton, a hæmal arch downward.

The vertebrate endo-skeleton first appears as an unjointed column,—*chorda dorsalis,* or *notochord,*—composed of cells which come to resemble those of cartilage. The centra of the vertebræ are formed around this notochord.

The axis of the vertebral column consists of spinal column, with its cranial enlargement, and the bones of the face and chest, which are modified hæmal arches. All other parts of the skeleton are appendages to this,—branches of this stem. There are never more than two pairs of limbs.

Vertebrata include fishes, reptiles, birds, beasts, man. To suit their various conditions of life, the vertebral type is modified in many ways. Either pair of limbs may be omitted, or applied to different uses. The fore-limb may be a fin, a wing, a mere leg, or an arm, ending in a sensitive and versatile hand. These variations depend mostly on the medium the animal is to live in,

and the nature of its food. These determine its habits and instincts.

THE HUMAN SKELETON.

a. Bones of the Trunk.

The *Human Spine* is adapted to the erect posture. Beside protecting the spinal cord, it supports the weight of the head and trunk, and is the axis of motion of the trunk. It gives exit to many nerves, and attachment to many muscles. It must be at once firm, flexible, yet not liable to bend too sharply, and elastic.

It consists of twenty-four separate vertebræ, seven of the neck, called cervical; twelve of the thorax, called thoracic, or dorsal, and five of the loins, called lumbar;—also of os sacrum and coccyx.

A vertebra consists of body or centrum, neural arch, and seven processes,—one spinous, two transverse, four articular. The body is composed of cancellated structure, coated with thin compact discs, which ossify separately; it is traversed by blood-vessels. Between the bodies of adjacent vertebræ are soft, elastic intervertebral cushions. These yield somewhat if we stand long, or habitually bend the spine to the same side. The spinous processes make a ridge along the middle of the back. The transverse give attachment to muscles, and in the thorax to ribs. The articular interlock with corresponding processes of adjacent vertebræ. Nerves go out through openings between the vertebræ.

The lumbar vertebræ are the most stout and square of any; their spinous processes are quadrilateral. The thoracic present smooth surfaces at top and bottom of their bodies, and on the front of each transverse process. These mark where ribs rest during life. The long,

sloping, spinous processes limit movement in this part. The cervical vertebræ have small bodies. Most of their spinous processes are split, to lodge muscles that hold the neck erect. Their transverse processes arise by two roots which soon meet and encircle an artery going to the brain. Their articular processes allow more movement than in other regions of the spine.

The first two vertebræ are peculiar. The first is called *atlas*, because like Atlas of old it holds up the globe of the head; the second is *axis*, because on it the head rotates. Atlas has no apparent body, and a very slight spinous process; it is a ring of bone. Its upper articular processes are changed to concave surfaces, matching convexities on the skull. Axis has a peg, or tooth-like process in front, which rises through the front part of atlas, and represents the body of atlas. This peg is connected by ligaments with the skull; and behind it a strong ligament crosses the ring of atlas, dividing that ring into two parts, one in front occupied by this peg, one behind giving passage to spinal cord.

Nodding motions take place between atlas and skull; rotating motions, between atlas and axis.

The bodies of the vertebræ are united by bands of ligament, and their arches by elastic straps which help to keep it erect.

A vertebra has usually three principal centres of ossification, and eight in all.

The lumbar vertebræ rest on os sacrum, which inclines backward. It is composed of five united vertebræ, consolidated to transmit the weight of the body to the lower limbs. The lines of union between these original vertebræ are marked by slight ridges, and by openings for exit of nerves. Os sacrum is very firmly wedged in between the two pelvic bones, joining them

by a rough surface, strengthened by ligaments, so that accidental separation is very rare.

Coccyx is the tail-piece of the vertebral column, conspicuous in most quadrupeds, in man a mere rudiment, composed of four vertebræ in reduced circumstances.

The great number of pieces in the spine, very firmly interlocked and tied by ligaments, give it the requisite firmness and limited movement, protecting the spinal cord, while yielding to necessary motions. Displacement of vertebræ is rare. Elasticity is secured by the numerous intervertebral cushions, and by the curves of the column. It curves forward in the neck, backward in the thorax, forward again in the lumbar region. These curves aid the erect position, and are slighter in lower animals. They add to the strength of the column. They depend mainly on the form of the intervertebral cushions.

Thorax.

Besides the thoracic vertebræ, the thorax consists of *sternum*, or breast-bone, and twelve ribs on each side, with the costal cartilages. It encloses the heart and lungs, and gives attachment to many muscles that move the arms.

Sternum is a broad flat bone in front of thorax. It consists originally of five pieces, which gradually unite; in middle life there are commonly three. The upper is notched at top to allow for the wind-pipe, and has a small cavity on each side for the collar-bone. Along the sides of the middle portion are notches for the cartilages of the ribs. The lowest piece is irregular in shape.

In many animals, sternum consists of numerous pieces, and its "typical form seems to be that of a series of distinct bones, one placed between each pair of ribs in front, as the vertebræ are behind."

The *ribs* are twelve on each side. Seven on each side, usually, are fixed to the sternum by their cartilages. The lower five decrease in length from above downward, and are called false ribs, their cartilages not reaching the sternum. The head of a rib lodges between the bodies of two vertebræ; a knob on the rib rests on the transverse process.

The body of a rib is flattened from above downward, and grooved behind its lower border for vessels and a nerve. The first rib is short, stout and fixed. The ribs are very elastic.

The cartilages represent sternal ribs found in many lower animals; are seldom ossified in man, before old age.

In forced inspiration the ribs are lifted (and slightly rotated), so that they separate more, and the transverse diameter of thorax is increased.

b. Bones of the Head.

The *skull* includes that portion of the vertebral column which is specially modified to lodge the brain, the more important organs of special sense, and the entrance to the alimentary and respiratory passages.

It consists of cranium, face, and hyoid bone. The *cranium* is the expanded summit of the vertebral column, reinforced by special bones which adapt it to its use as the chamber of the brain.

Above, it presents an oval dome, formed of flat bones of variable thickness, united by sutures. These are marked, outside by protuberances which were centres of ossification, and by ridges for muscles; inside, by folds of the brain. They present two layers of compact structure, with some cancellated between. The floor of cranium is uneven, with three divisions, corresponding to regions of the brain.

Several openings in this floor give passage to nerves and blood-vessels.

Eight bones enter into the human cranium.

1. *Occipital*, at back, presents foramen magnum, two condyles to fit the concavities of the atlas, a protuberance more marked in beasts. It is a modified vertebra. Its four portions are not ossified together at birth; they surround foramen magnum.

2. *Parietal* bones, two, form the side-walls of cranium, enclosing the middle lobe of cerebrum, and nervous centres of sight and hearing.

3. *Frontal* is bone of forehead and roof of orbits, its two parts separated by a sharp projecting ridge. Above this ridge are air-cavities, the frontal sinuses, continuous with the nostrils, variable in depth. Orbitar plate is thin, and the brain may be wounded through it. At its outer part, is a hollow for the tear-gland. Frontal is developed from two centres, and the parts are not united in children.

4. *Temporal* bones, two, form the temples. Note, temporal ridge, outer and inner openings of the ear, cavities to make the joints of the lower jaw, zygomatic processes. It consists of three portions (which in many lower animals are distinct bones), the squamous, mastoid and petrous.

Squamous forms the bony wall of the temple; thin, but protected by muscle.

Mastoid projects to give attachment to a large muscle, and is hollowed into cells opening into the inner cavity of the ear. Eustachian tube supplies air to this cavity and the cells,—which aids in hearing.

Petrous lodges the internal apparatus of the ear.

5. *Sphenoid* bone is wedged in at the base of the skull between the other cranial bones, joining them all. It enters into the base of the skull, orbits, temples and nostrils. In shape it resembles a bat. Its body is viewed as a continuation of the centra of vertebræ. It is hollow, containing air in cavities continuous with the nostrils. The greater and smaller wings give passage to nerves and blood-vessels, through several openings, and extend up into the temples. The plates (pterygoid) which represent the bat's legs, give origin to muscles used in chewing.

6. *Ethmoid* bone lodges the nerves of smell. Its cranial portion presents two surfaces riddled with numerous openings for these nerves. Between these rises a sharp ridge. This is continued down in a perpendicular wall which partly separates the two nostrils. Ethmoid forms part of the inner wall of each orbit, and between the two orbitar plates are ethmoid cells, lined by delicate membrane and supporting the nerve-branches of smell.

The air-cavities in several cranial bones are extensions of the nostrils. The air in them modifies the voice by its resonance.

The cranial sutures on the top are jagged, on the sides are bevelled. They somewhat deaden shocks.

Fracture of the cranium is dangerous, from involving the brain. In early life, the outer plate may be depressed into the cancellated structure beneath.

The *Bones of the Face* are mostly connected with the organs of eating, and the senses most associated with eating. There are fourteen.

Upper maxillary bones, two, form the centre of the face, floors of the orbits, sides and floors of the nostrils, and most of the roof of the mouth. The body is hollow, making another large air-cavity. The semicircular palate-plate is bounded by a ridge that bears the upper teeth.

Firmly attached to different parts of the upper maxillary bones, are the other bony pieces of the upper portion of the face. Two (*nasal*) make the bony support of the bridge of the nose; two (*lachrymal*) form canals to drain tears down into the nostrils; two (*malar*) form the prominences of the cheeks, and front of the zygomatic arches; two complete the bony roof of the mouth (*palate*); two project like scrolls from the outer walls of the nostrils (*turbinated*); one divides the two nostrils (*vomer*).

Opposed to the upper maxillaries is the only movable bone in the skull, the *lower maxillary*. It consists of body and a perpendicular part named ramus. On the body we observe the middle ridge, marking where the two halves united; the chin; and two oblique ridges, one in front, one behind. These divide the alveolar part, which contains the sockets of teeth, from the basilar part. In infants, only the alveolar part exists, to give firmness to the mouth; while in old age, the alveolar part disappears.

The ramus rises from an angle, often strongly marked by muscles. It presents a pointed process to receive the temporal muscle, and a rounded process surmounting a neck, by which this bone makes a joint with a cavity in temporal bone. The form of this joint varies in different animals with the food; and in man, it is intermediate between that of the strictly carnivorous and of the herbivorous animal.

Of these two portions of the skull, cranium is proportionally larger in the more intellectual races of men and animals; face in those where the senses and animal instincts most predominate.

Mere inspection shows many characteristics. Strong muscular ridges on the outside of cranium are an animal character. The temporal ridges rise to the median line in many beasts, and near it in some very ancient human skulls.

Inspection shows the general form of the skull. Looking at it from above, we ask, Is the skull a broad oval, or long and narrow? Are the nasal bones and zygomas visible?

Looking from below, we note position and obliquity of occipital foramen, curve of zygoma, form of palate, &c. Anterior border of occipital foramen should be midway of base of skull.

Sawing down a skull near its median line, the eye appreciates comparative area of cranium and face.

But accurate science calls for means of comparison that admit of numerical statement.

The best-known attempt at reducing the comparison of cranium and face to numerical expression, is in the *facial angle* of Camper (1722–1789). Draw one line from front of upper jaw to front of forehead, and one from opening of ear to some fixed point on upper jaw, say the roots of upper front teeth. The angle between will be more acute as the jaw projects and forehead retreats. In good European skulls, it may be 80° or more; in many negro skulls, it is 70° or less; in adult apes, not over 40°. The prominence of the jaw which diminishes this angle is called *prognathism*. This angle gives only an uncertain approximation.

We may compare the proportions between length and width of cranium. Length is measured from the most prominent point in the middle of the forehead to that of occiput; width, across the parietals at broadest part.

$$\text{Index of breadth} = \frac{\text{Transverse diameter} \times 100}{\text{Antero-posterior diameter.}}$$

Skulls where this index is more than 80 (or 83) are called *brachy-cephalic* (short and wide); where much less than 75, they are *dolicho-cephalic* (long and narrow). Prognathous skulls are generally long and narrow.

The classification of skulls, and of varieties of the human species, is not settled. But several leading anthropologists make three great divisions of mankind. Three main types of skulls, corresponding to this classification, are the *oval*, *pyramidal*, and *prognathous*.

The oval or elliptical, viewed from above, shows an oval outline, with no part projecting much beyond the cranium, forehead more high and broad than in other types, the nasal bones more arched. This is most common in the leading European nations.

In many skulls, the broad, projecting zygomas, forehead receding and tapering upward, and high apex of the cranium, give a pyramidal character to the whole. The nasal bones are rather flat. The pyramidal skull is found in the Mongolian nations, the Esquimaux, and somewhat modified in the aborigines of this country.

The prognathous type is marked by projecting teeth and jaws, with the cranium long and laterally compressed, the forehead retreating, the origin of the biting muscles high and extensive. This is most marked in the native Australians and negroes.

Teeth.

Man has two sets of teeth, the temporary and the permanent. The permanent teeth are 32,—16 in each jaw, viz., 4 incisors, 2 canine, 4 bicuspid or premolar, and 6 molar.

The temporary teeth are only 20,—viz., 4 incisors, 2 canines and 4 molars in each jaw. These usually begin to appear at the age of about six or seven months. The two middle incisors of the lower jaw usually appear first; the last of this set, at two or three years old. The temporary teeth last till the growth of the jaws renders them too small.

The permanent teeth begin to appear at the age of six or seven years, usually. The full set is not completed till the age of manhood; and in some, the four last molars, or wisdom teeth, never show themselves.

The incisors or front teeth are named from their cutting edges, being broad and comparatively thin. The canine are conical with blunt points. The bicuspids are the first teeth with grinding surfaces, or uneven projections and hollows. They are called premolars, from being molars which have their representatives in the temporary set. The molar or true grinding teeth have more extensive and rough grinding surfaces.

DENTAL FORMULA OF MAN.

$$\text{i.}\frac{2-2}{2-2} \quad \text{c.}\frac{1-1}{1-1} \quad \text{pm.}\frac{2-2}{2-2} \quad \text{m.}\frac{3-3}{3-3} = 32$$

Piercing and cutting teeth characterise carnivorous animals, while highly developed grinding teeth mark the herbivore. Man has both, and is therefore adapted for a mixed diet.

Three different substances enter into the formation of a tooth,—dentine, or ivory, enamel, bone. Dentine, or ivory, consists like bone of an animal basis in which mineral particles are deposited. It resembles bone in chemical composition. A long cavity occupies the centre of the tooth, and holds its nerves and blood-vessels. From this cavity, numerous wavy tubes run out toward the surface of the tooth, dividing as they go. These convey a colorless liquid containing the nutriment needed for the dentine.

Enamel covers the projecting part of the tooth. It is the hardest substance in the body, containing less than four per cent. of animal matter. It is composed of six-sided cells passing from dentine to the surface. When removed it is not renewed. It is injured by strong acids, by heat and cold. The root of each tooth has a thin covering of bone.

The teeth are a part of the apparatus of digestion, but are described here because of their importance in comparative anatomy. Their structure and arrangement bear a close relation to the nature of the food, the digestive powers, the form of the limbs, the habits and disposition of the animal. Even the microscopic anatomy of a fossil tooth may enable us to reproduce the entire form.

Os hyoides, or lingual bone, is named from its resemblance to the Greek U. It supports the tongue, and the entrance of the respiratory passages; and corresponds to the arches that support the gills of the fish (*branchial skeleton*).

c. BONES OF THE LIMBS.

If we regard the axis of the skeleton as composed of segments, each consisting of vertebræ with neural and hæmal arches more or less developed, the remaining portions, or extremities, are to be regarded as appendages to this axis.

The Upper Extremities

are united to thorax by the shoulder-girdle. This consists of two bones, scapula and clavicle.

Scapula, or shoulder-blade, is the triangular bone on the outer and back surface of thorax. It presents (1), a ridge which ends in the acromion, or point of the shoulder; (2), coracoid process, curving forward like a half-bent finger, and representing an important distinct bone in birds and reptiles; (3), the shallow cavity to form the shoulder-joint (*glenoid*). Other bony parts strengthen this joint. Scapula is loosely joined to the thorax by muscles, and makes a movable fulcrum for the motions of the arm.

Clavicle, collar-bone, extends from top of sternum to acromion. It braces out the shoulder, resisting those muscles that draw the arm inward. Animals that use the fore-leg only for support have no clavicles. Scapula and coracoid are the most constant elements of the shoulder-girdle. Clavicle is easily fractured, by indirect violence.

Humerus is a good specimen of the long bones. Its rounded head articulates with the glenoid cavity of scapula. Near it are marked protuberances for muscles. At the lower end are a pulley to form the elbow-joint, and two large knuckles (condyles).

The fore-arm contains two bones, *ulna* and *radius*. Ulna is large at the upper end, and forms most of the elbow-joint with humerus.

Ulna lies along *inner* side of the fore-arm. At its upper end, are a great notch to lodge the pulley of humerus, a small notch for the head of radius to roll in, and a large process behind forming the point of elbow. At its lower end it is small, and presents a pointed process. Radius has a small round head that rolls in the small notch of ulna. Its lower end is broad, and rolls on the tip of ulna, and forms most of wrist-joint.

The wrist, or *carpus*, is composed of eight little bones, lying in two rows, firmly bound together, and curved to protect nerves and blood-vessels of hand. Elasticity is gained by its division into numerous bones.

Metacarpus contains five long bones. Only that of the thumb moves in all directions, freely, and can be opposed to the fingers.

The finger bones, *phalanges*, are 14,—2 in the thumb. 3 in each finger. These are flattened on their front surface, with raised edges. The last row end in rounded ridges, to support the nails.

The general direction of the hand is determined by movements of the larger joints; its nicer adjustments are made in the joints of the wrist and hand. The shoulder is a universal joint; it is greatly strengthened by bony processes, ligaments and muscles; yet is easily dislocated downward. The elbow is a hinge-joint. In rotating the hand, radius, turning on ulna at top and bottom, carries the hand with it. The thumb adds greatly to the uses of the hand, by its free motion in all directions, and by being opposed to the fingers.

Pelvis

transmits the weight of the body to the lower limbs. It forms a solid arch. Os sacrum is the key-stone of this arch, supporting the spine; the sides of the arch consist of two bones, the right and the left *os innominatum.* This bone consists of three portions, ilium, ischium and pubes,—which meet in the socket of the hip, and become united in youth. It presents, (1) a spreading crest above, prominent in life, and from which spring the muscular walls of abdomen; (2) a rough surface to join os sacrum; (3) arch (of pubes) in front; (4) deep socket of hip-joint.

A prominent line, running along the thickest part of these bones, divides the main abdominal cavity above from *true pelvis* below. True pelvis is oblique to axis of trunk; it thus supports better the weight of internal organs, in the erect posture. Not oblique in quadrupeds.

Pelvis differs in the two sexes. In the female, it is more broad and shallow; its outlet is more open; the arch of pubes more rounded; os sacrum less curved.

The pelvic-girdle corresponds to the shoulder-girdle.

The Lower Extremities

are remarkably analogous to the upper.

Femur is the longest bone in man, not in the quadruped. It presents the same essential points as humerus. The head is much more prominent, making more than half a sphere, and borne on a neck which gives the body a wider basis of support. Its muscular protuberances and ridges are more marked; the condyles at lower end much larger. The neck runs a little forward from the shaft, giving the foot an outward turn. The prominent head fitting into a deep socket, both lined by moist and

elastic cartilage, is held in place by atmospheric pressure, and swings freely; the muscles guide it, but are not needed to support it.

Patella (knee-pan) protects the knee-joint in front; it is developed in the extensor tendon.

The leg contains two bones immovably united. *Tibia* is the larger; its head forms the knee-joint; its front surface and edge make the shin. *Fibula* is very slender.

The ankle, or *tarsus*, contains seven bones. One (astragalus) has a pulley-like surface above, which rises between the projecting tips of tibia and fibula, to form the ankle-joint. The heel-bone projects backward to make a support in standing, and a lever by which the muscles of the calf raise us on tiptoe.

The five metatarsal and fourteen toe-bones (phalanges) correspond to the metacarpal and finger-bones. They are adapted to firmness and elasticity, rather than freedom of movement. The great toe is slightly opposable, but very limited in motion. The foot forms a double arch, from heel to toe, and from side to side.

The two pairs of limbs are formed on the same plan, so modified, in the *upper*, as to give great range of movement, for prehension and touch; in the *lower*, to gain firmness in standing and walking. The free motion of the shoulder in all directions, its loose connection with the trunk, the rotating hand, the long fingers with their numerous joints, the opposable thumb,—all concur to make man's hand the most perfect mechanical instrument of mind. The firmness and limited movements of the hip, the wide pelvis, the tibia with its broad top and close union with fibula, the large tarsal bones, prominent heel, and broad arched foot, set at right angles to the leg,—all favor erect posture and forward progression.

Joints.

The union between bones may be movable or immovable. The second is seen in the cranial sutures; the first, in the *joints*. The expanded ends of bones are here covered by a thin layer of elastic cartilage, and united by a thin membrane, white, smooth, and lubricated by a glairy liquid. This liquid is named *synovia;* and the membrane is *synovial membrane.* Between this and the articular cartilages, is the cavity of the joint. The bones are held together by ligaments, formed of strong, white, glistening fibres. The cartilages give elasticity and deaden shocks; the synovial membranes obviate friction; the ligaments limit movement and oppose displacement.

Joints may allow only a gliding motion, as in the wrist, or may resemble hinges, as the elbow, or may be universal joints, as the shoulder and hip. These last have a cylindrical or *capsular* ligament, which embraces the two bony surfaces that compose the joint.

Shoulder-joint. The glenoid cavity is deepened in life by a rim of cartilage. The processes of scapula, with ligaments passing from point to point, fortify the joint. The surrounding muscles aid in this.

Hip-joint presents a more convex head and a deeper cavity, deepened in life by cartilage. The capsular ligament includes most of the neck; a special ligament connects the head with the cavity and conveys blood-vessels to the head; atmospheric pressure aids in preventing displacement.

The knee is a very complicated and extensive joint, with special internal arrangements for elasticity, firmness in standing and limited movement. It is a loose hinge, bending in only one direction.

Comparative Anatomy of the Skeleton.

This subject will be more or less fully illustrated in the lectures, by specimens of the leading types, especially of Mammalia, with comments, and some reference to the principles which govern the variations of the vertebrate skeleton.

MUSCLE.

Muscle is the chief *active* organ of animal movement. Its most familiar form is common red meat. This consists of bundles of fibres nearly parallel, held together by a delicate web of *connective* tissue,—the common packing of the body. The fibres are composed of fibrils; and each fibril, when microscopically examined, appears crossed by dark lines. The lines are called *striæ;* and this kind of muscular fibre is hence named *striated.*

The bundles of fibres are united into distinct organs, or muscles, each having its own form, attachments, name, and uses. There are more than four hundred muscles in the human body.

Such are the external muscles of our limbs and trunk. In the internal hollow organs, there are muscular fibres of simpler structure, each fibre being an elongated cell, not striated, serving to move the contents of those organs. Thus, the stomach has fibres in its walls that keep the food tumbling about, that it may be fully dissolved. The heart, though a hollow organ, has striated fibres.

Muscles act by their fibres contracting, or shortening, and so drawing toward each other the parts to which their ends are fastened. In so doing, they swell and harden. Generally, one end is moved, while the other remains fixed. The fixed end is called origin; the movable end, insertion. Most muscles move bones, and are

inserted by means of white, silvery, firm and inextensible cords, named *tendons*, continuous with the periosteum. Some tendons take the form of broad, membranous expansions.

Muscular contraction depends immediately on the contractility of protoplasm in the fibres. It may be excited by various agents, as electricity. It is usually stimulated through the nerves. Electricity will make a muscle contract, whether applied to its fibres, or to the nerves that go to it. In voluntary motions, the will acts through the brain, and sends its mandates to the muscles through the nerves. Thus the mechanical apparatus of bone and muscle is brought under control of our minds.

All muscular action requires rest; the internal organs act only at intervals, even the heart resting after every beat; while voluntary motion brings on fatigue which enforces rest. Not all the fibres of a muscle are in action at once; they take turns.

Power is often sacrificed to range and velocity of movement, and grace of form. In the limbs, most muscles run nearly parallel to bones, and tend to pull one bone against another. The processes lessen this disadvantage.

The three kinds of levers are all exemplified in the human body. First, P. F. W. (or fulcrum between power and weight), is seen in the head poised on the spine; second, P. W. F., in the act of raising ourselves on tiptoe. The third, F. P. W., is most common, as in biting, or lifting a weight with the hand. The more such a lever is lengthened beyond P., the more force will be needed to raise a given weight, but extent of motion is also increased.

Muscles sometimes oppose displacement, or prevent movement instead of causing it. They may act against gravity, in upholding the body. Man's skeleton is adapted to the erect posture, but this can only be maintained by muscular action. The foot being the base, the leg, thigh, pelvis, spine and head form successive segments, balanced by the opposing action of flexor and extensor muscles.

Elastic ligaments aid in support, and relieve the muscles.

In walking, each lower limb swings like a pendulum, its head being held in its socket mainly by suction. The natural gait depends on length of limb. Each limb represents the spoke of a wheel with a portion of tire, and these two sections of a wheel are alternately lifted and swung.

Muscular Anatomy in relation to **External Form and Art.**

The muscles determine in great degree the external outlines. Hence a knowledge of muscular anatomy is valuable to the sculptor or painter, who would represent action or feeling, and also to the student of art. This knowledge includes both an acquaintance with the individual muscles, and with the different appearances they produce when contracted or relaxed.

The muscles of the limbs are covered by *fascia*, a membrane formed of condensed connective tissue strengthened by white fibres. This limits the swelling of muscles in contraction. Over this, is a soft padding of less dense connective tissue, filling the interstices, and containing more or less fat. Over all, is the skin. These coverings partially conceal the muscular lines and ridges. These lines are more prominent in those who exercise the muscles much; less so in women and children.

Some artists have shown their knowledge of muscular anatomy too freely, making the separate muscles too prominent.

Muscles of the Face.

The muscles of the face furnish a natural language of expression, and are therefore interesting to the student of art, and the observer of human nature. They are attached to the skin, in which they produce more obvious wrinkles than most other muscles; hence they leave traces which betray the habits and daily temper. Some of them have little use except as muscles of expression.

Two muscles wrinkle the forehead: (1), the *frontal*, really a part of occipito-frontal, which extends from occiput, is tendinous on top of the head, and is attached to the skin of the forehead. It arches the brow as in surprise, and produces transverse wrinkles, signs of care and thought. (2). The frowning muscle (corrugator supercilii) arises from upper and inner angle of orbit, and passes up and outward to the skin of the brow.

Orbicularis palpebrarum encircles the lids, closes them as in winking, and puckers them in laughing and crying.

Three *elevators of the mouth* rise from upper jaw near orbit and pass down to upper lip and corner of mouth, and raise these parts. The first, acting also on the side of the nostril, may express contempt. The three act in laughing. Two slips passing from cheek-bone to corner of mouth act in laughing, and also expose the canine teeth, and are large in carnivores.

Opposed to these elevators are two depressors, rising from the lower jaw and inserted to the lower lip and corner of the mouth. These express stern or sad feelings; a man is "down in the mouth."

The pouting muscle rises from lower jaw beneath the

incisors, and passes downward to the skin of the chin. This muscle acting with the depressors of corner of mouth arches the lower lip.

Orbicularis oris encircles the mouth, closely connected with the skin. Its fibres are continuous with those of the muscles just described; it opposes their action, and makes a close-mouthed man; a "stiff upper lip." It yields to those muscles, when the emotions they express overcome our powers of restraint.

In laughing, *orbicularis palpebrarum* is contracted, *orbicularis oris* is relaxed; the elevators of mouth are contracted. In weeping, *orbicularis palpebrarum*, the frowning muscle, and depressors of mouth are contracted, and between them the face is furrowed and distorted.

There are two powerful biting muscles, *temporal* and *masseter*. The first, arising from temporal ridge and squamous part of temporal bone, passes beneath the zygoma, and is fastened to the pointed process of lower jaw. The latter passes from zygoma to angle of jaw. Both raise the jaw, and the latter gives it a movement forward and backward.

Muscles of Respiration.

The chief agent of inhalation is the *Diaphragm*. This arises from lower boundary of bony thorax, from tip of sternum, lower ribs, and front of lumbar vertebræ. Its fibres pass up and inward, forming a dome within the bony thorax, and are inserted into a tendinous centre, the summit of this dome. It is thus a movable partition, or roof to abdomen and floor to thorax, pierced by various openings. When its fibres contract, it is drawn downward, enlarging the cavity of the chest.

Other muscles aid in forcible inhalation, raising the

ribs, and carrying the lower part of sternum forward. The *intercostals* make two layers between each successive pair of ribs. The external run down and forward; the internal, down and backward. The first rib being fixed, they lift the ribs. Several muscles common to the arm and thorax, may help lift the ribs, in labored breathing.

Expiration depends mostly on the elasticity of lungs and costal cartilages, (also ribs and sternum,) aided and regulated by the *great abdominal* muscles. Three pairs of muscles spring from the bony boundaries of abdomen, ribs, pelvis and lumbar vertebræ, pass forward and wall in the great abdominal cavity. They become tendinous in the middle, forming a white expansion from sternum to pelvis. These muscular layers cross each other in different directions as they pass toward the central tendon. The outer layer runs down and inward from ribs to pelvis and median line; the next layer, mostly upward and inward from pelvis to median line and ribs, though its lower fibres arch downward; the inmost layer is transverse. A straight muscle runs vertically between pelvis and sternum, in a sheath formed by the fibres of the common broad tendon.

The median line of abdomen is called the white line (linea alba); and two or three cross-lines mark tendinous intersections in the fibres of the straight muscle (transverse lines). These lines are important in sculpture.

The great abdominal muscles act in expiration, and especially in such modified expiratory acts as coughing, sneezing, and laughing, and in speech. They are the chief antagonists of the diaphragm.

Some other muscles aid in expiration.

Respiration is more performed by the diaphragm in men; by lifting the upper ribs in women.

Voice.

Voice is produced in the *Larynx*. This is a cartilaginous box at top of the wind-pipe. The largest cartilage is named *thyroid*, which forms a notched prominence named Adam's apple. Its two sides meet in front at an acute angle. Its upper border is connected by membrane with the lingual bone. Beneath this is the *cricoid* (shaped like a seal-ring); its widest part is behind, and bears on its top two small *arytenoid* cartilages, shaped like three-sided pyramids spirally twisted. Their bases form joints by which they rotate on cricoid.

The *vocal cords* are two strong elastic bands, less than an inch long, stretched from each arytenoid forward to the angle of the thyroid, and covered by membrane. The chink between these cords is called *glottis*, wider behind than in front, and narrowing when we breathe out. To produce vocal tone, the cords are brought close together and parallel, and are set in vibration by the expired air. Changes in tone are produced by changes in the length, tension and position of the cords. These changes are made by the action of several small muscles. The thyroid may be moved on the cricoid, or the two arytenoids bent toward each other, or carried backward or forward. The whole larynx also may be lifted or depressed.

The larynx lies beneath and in front of the throat, and communicates with it by an orifice behind the *epiglottis*, a movable leaf-shaped valve behind the root of the tongue. This guards the opening of the larynx when we swallow, and affects the voice.

The lining membrane of the larynx is very sensitive.

Voice is produced by the vibration of the cords, and of air in the passages above and below them. Its qualities are modified by various influences:

1. The depth and force of respiration. Breathing by means of the diaphragm and abdominal muscles gives best command of voice.

2. The resonance of air in the air-passages,—throat, mouth, and cavities of the head.

3. The state of the lining membrane. Hoarseness, or loss of voice, may come from swelling of this membrane.

The Effects of Muscular Exercise

are partly *local*, partly *general*.

The muscle not only changes form, but very slightly lessens in volume. More blood comes to the part. The blood leaving a muscle during contraction is darker and chemically altered. The local temperature is increased. A slight breezy murmur accompanies contraction.

If properly nourished, the muscles gain in volume, color, strength and dexterity. The bones enlarge also,—in the trunk as well as limbs.

General Effects.

1. It quickens *circulation* of blood. The muscles form nearly half of our weight, and are very vascular. When exercised they demand more blood, and the heart beats more frequently or harder, to supply this demand. Exercise, by drawing more blood to the muscles, may relieve internal organs, especially the brain. But if continued or violent, it excites the heart's action. Muscular contraction presses blood from the smaller blood-vessels toward the heart. Hence a danger of excessive exertion. The heart may be distended to excess. A very rapid or intermittent pulse shows danger.

2. It quickens *breathing*. More CO_2 is formed and thrown off. Animal heat is increased. Panting from

exercise shows excess. Straining efforts require us to hold the breath with lungs distended; this may produce various accidents.

3. It increases *perspiration.* Anything that checks evaporation, as water-proof clothing, makes exercise difficult. Evaporation of sweat is the natural mode of moderating excess of heat. While the heated skin is being thus cooled, cold and currents of air may be dangerous.

4. It creates increased demand for food, promotes appetite and rapid digestion. Not if violent soon after a meal.

5. It exhilarates and clears the *mind,* makes it less easily disturbed by outward influences, and wins good sleep.

Deficient exercise, with abundant food, causes muscles to degenerate, till they are more or less replaced by fat; with deficient food, it makes one liable to tubercular disease, or disorders those organs by which blood is purified. Excessive exercise long continued is likely to shorten life, by injury of lungs, heart or large blood-vessels.

Practical Suggestions.

1. During exercise, lungs should be free to expand. Clothing not tight about chest.

2. Where many persons exercise together, open air or free ventilation is needed.

3. Exercise should be symmetrical and varied; employ upper and lower limbs, right and left sides.

4. Special feats of strength require gradual training.

II. Nutritive Functions.

1. Food and Digestion.

The uses of Food are:

1. To supply material for sustenance and growth.

2. To supply material for the development of force,—heat, muscular power, &c.

3. To stimulate and aid the powers of digestion.

1. Food must contain all the chemical elements found in the body, in quantity enough to repair waste, and provide for growth. At least fourteen elements exist in the body,—chiefly C, O, H, N, Ph., S., Ca., Fe. But these elements are combined into compounds, called proximate principles of food, or alimentary principles. These are intermediate between chemical elements and compound foods or alimentary substances. Proximate analysis reveals alimentary principles; ultimate analysis reveals chemical elements.

The proximate principles of food may be variously classified. We may consider them in five groups: the albuminous, fatty, sugars, mineral substances and water.

a. Albuminous, as white of egg, the curd or casein of milk, and gluten of flour. These contain C, O, H and N, and it is only this group that always contains N. Hence these are known as nitrogenous principles; and, as N is an essential element in animal tissues, they have been regarded as especially tissue-forming compounds. But it is proved that other proximate principles are also necessary to nutrition; and that albuminoids contribute to the production of force, by oxidation of their C and H. The classification of Liebig, which distinguished

these as plastic or tissue-making, is not therefore strictly correct.

b. Fats and oils. These consist generally of C and H, with a small proportion of O, and are called hydrocarbons; being thus highly oxidisable, they are of great importance in the production of heat and other forms of force. But they are also essential to the nutrition of the tissues, especially of the nervous system, and of the fatty tissue, which makes a reserve-fund to aid nutrition, when food is insufficient or is not well-digested, or when wasting disease exists.

c. Sugars and starches. These consist essentially of C+H and O in the proportions necessary to form water. They are called hydrates of carbon. Being less oxidisable than fats, they are not so good heat-producers, and are more liked in hot seasons and climates. Rice, a staple food in hot countries, contains 85 per cent. of starch. Starch contains granules which have to be broken down and converted into sugar, to become soluble.

d. Mineral compounds. Chloride of sodium is necessary to aid in many chemical and physical processes of life. Phosphate and carbonate of lime are required for the bones and teeth; phosphorus, for the nutrition of brain and nerve; iron, for the blood, &c.

e. Water is the general solvent and carrier, found in all the textures, and necessary to their proper consistence.

One use of this classification is to explain and suggest useful combinations of food,—as, the addition of butter to bread, potatoes to meat, &c.

Healthy diet requires specimens of each group; though the sugars may be converted into fat, and so replace fatty food. Milk, the natural food of the young, contains representatives of each group.

2. Force is produced by the oxidation either directly of alimentary principles, or of the wasting material of tissues. Heat and mechanical force come from slow combustion, as in a steam-engine from quick combustion. Oxidation of C produces CO_2, which is discharged from the lungs and skin, and in greater amount when we exercise much.

Nervous and mental force require oxidation of the elements, either of food or of nervous substance.

The mechanical power evolved in muscle was formerly ascribed to oxidation of the material of the muscles themselves. It is now attributed rather to oxidation of C and H in the food.

3. Food aids digestion in various ways. It furnishes the elements, and excites the flow, of liquids useful in digestion. It stimulates the muscular action of the stomach and intestines by its bulk and coarseness. The mineral principles aid in the absorption of nourishment.

Alimentary *substances* may be animal or vegetable. Animal foods, speaking generally, are more rapidly digested, more exciting, and contain a larger proportion of nitrogenous principles and fat, than vegetable foods. Health may be maintained by exclusive vegetable diet; but the teeth and digestive organs of man fit him for a mixed diet, and common experience and natural appetite favor its use. Wheat flour, the richest in albuminous principles of the vegetable foods, is deficient in fatty ingredients, which are therefore added to bread in the form of butter. Indian corn is rich in albuminoids, and contains more fat. Bread retaining the bran is more stimulating to the muscular coats of stomach and intestine. The bran also contains a larger proportion of phosphates than the interior of the grain.

Digestion.

The object of digestion is to prepare food for absorption into the Blood. Its seat is the mucous membrane of the alimentary canal. This canal consists of mouth, pharynx, œsophagus, stomach, small and large intestines.

Œsophagus passes from pharynx in front of spine, through diaphragm, to the stomach.

The stomach and intestines form a tube with three important coats. Inside, is mucous membrane, an inverted continuation of the skin. Middle coat is muscular, some fibres running lengthwise, others transversely. Outside, is the serous coat, one of those slippery membranes which line the closed cavities of the body and cover the organs within them. The serous membrane of abdomen is *peritoneum;* it lines the abdominal walls, and is reflected over the contained organs. On entering the abdomen, the canal dilates to form the stomach. The entrance to this bag is called cardia; the exit, pylorus. From the pylorus, the small intestine begins, and forms a tube about twenty feet long, coiled in the abdominal cavity, and connected to the walls of the body by a double fold of serous membrane, called *mesentery*, through which the blood-vessels of the intestine run. The mucous membrane of both stomach and small intestines contains very numerous minute depressions, some of them branched, which pour out liquids useful in digestion. It lies in folds; and in the small intestine presents little velvety eminences called *villi.* The first portion of this intestine, less movable than the rest, is called *duodenum.* At the lower right-hand corner of abdomen, the large intestine begins, by a valvular opening. It thence passes up on the right, across beneath the stomach, and down on the left, ending in the rectum.

Certain liquids, useful in digestion, are poured into the alimentary canal, at different points, from separate organs.

1. Saliva, prepared by the salivary glands,—parotid, submaxillary and sublingual.

2. Bile, formed by the liver, enters the duodenum, through the gall-ducts.

3. Pancreatic fluid, from the pancreas, enters very near the bile. This fluid resembles saliva.

In the mouth, food is chewed and mixed with saliva, an alkaline fluid, which lubricates it, and converts some of the starch into soluble sugar.

Very soon after food enters the stomach, a clear acid liquid begins to be poured out from its mucous membrane. This is *gastric fluid.* It has power to dissolve meat and albuminous food, and render them more fit to be absorbed and converted into tissue, more soluble and diffusible.

Its powers depend on union of an acid, usually H.Cl., with an animal substance (ferment) named pepsin. Its power is limited; but flow of gastric fluid is increased by presence of food. Its power is aided (1) by previous reduction of food by chewing; (2) by heat of the body; and (3) by movements of stomach, which keep the food rolling about, that the gastric fluid may act on every part. The time occupied by gastric digestion varies with the kind of food, its preparation by cooking and by chewing, and the state of the stomach. Fatigue of body or mind, depressing or angry emotions, check the flow of gastric fluid. Cheerful feelings and light occupations befit the hour. Cooking should soften food, and so modify it that chewing shall prepare it for solvent action of stomach. The flow of gastric fluid may be increased by stimulating condiments. The stomach should

rest after a meal, before it is again called on to prepare its secretion. A good deal of water is absorbed by the veins of the stomach, so that its contents become less liquid. They pass to the small intestine in a semi-fluid state, containing undissolved fragments.

Beside many experiments with gastric fluid and pepsin, outside of the body, digestion has been directly observed in the stomach, laid open by accident in human subjects, or experimentally in animals.

In the small intestine, digestion is continued. Bile and pancreatic fluid enter the duodenum, very near the stomach. The uses of bile in digestion are not well known. Pancreatic fluid acts on all the principal classes of proximate principles. It helps to dissolve albuminous foods, by means of a ferment, pancreatin, united with an alkali. It converts starch into soluble sugar, much more actively than does saliva. It converts fat into a milky mixture or emulsion (*chyle*) capable of absorption into the blood. Other liquids poured from the mucous membrane of intestine aid in thus reducing different forms of food to soluble form.

Chyle is absorbed from small intestine by a special set of vessels called *lacteals*. It represents mostly the fatty foods,—not perhaps exclusively. The solution of albuminous, sugary and other foods in water is mainly absorbed by the blood-vessels of the intestine. The muscular coat of the bowel is stimulated to action by its contents. This movement passes along in waves, or in a vermicular manner, and is called peristaltic motion. It is promoted by bulk of food, by the presence of substances not themselves digestible, and by exercise of the muscles of the abdominal walls.

Digestion is essentially completed within the small intestines.

Bile retards decomposition in the food, and stimulates peristaltic movement.

2. Absorption.

The nutritive parts of food enter the blood in two different ways; part being absorbed directly by the blood-vessels of the intestine, part through the circuitous channel of the lacteals. The confluence of the lacteals forms the *thoracic duct*, which ascends in front of the spine, till it pours the chyle into the blood, a little before that fluid is to enter the heart. In the mesentery, the lacteals pass through numerous glands, in which chemical changes occur, bringing chyle to resemble blood more and more.

The surface for absorption is much increased by little velvety eminences, called *villi*, thickly spread over the mucous membrane of small intestine. "They hang out into the nutritious, semi-fluid mass contained in the intestine, as the roots of a tree penetrate the soil." Each of the villi contains the commencement of a lacteal; so that the interior of the lacteals is separated from the intestinal contents only by a very thin tissue, capable of absorbing liquids freely, by the process called osmosis.

The lacteals are part of the great system of lymphatic vessels, which are found all over the body. These converge from all regions till they reach the thoracic duct, so that the fluid they contain (lymph) enters the blood with the chyle. This transparent fluid contains chemical products of waste of tissues, which are poured into the blood, there to undergo new chemical changes,—perhaps to become again nutritive, or to develop force by oxidation. The lymphatics, like the lacteals, pass through numerous glands which modify the liquid within them.

The same channels that serve for normal absorption may introduce foreign substances, as poisons, into the blood.

Substances are most readily absorbed, when brought close to the absorbing vessels; hence more easily through mucous membrane than skin, since it is thinner; and still more, when inserted beneath the skin. Hence an advantage of the thinness and delicacy of the villi.

Absorption is less rapid when the blood-vessels are well filled.

Poisons will affect the system sooner in a hungry person, than when the veins have just been replenished with food.

3. Blood, and its Circulation.

Blood is a liquid with solids floating in it. These solids are microscopic cells, of two kinds, the *white* corpuscles, and the *red*. The red are much most abundant.

White corpuscles are nucleated cells, of changeable shape, contractile and composed of protoplasm. They vary much in number, being more abundant after eating. Their origin is uncertain.

Red corpuscles (a cubic millimetre of blood contains say 5,000,000 red corpuscles) are not nucleated, are flattened, disc-shaped, normally circular in most mammalia. Birds, reptiles and fishes have red corpuscles, larger and nucleated. Diameter, in man, say $\frac{1}{3000}$ inch. They contain the coloring matter of blood, and are made brighter in color by meeting with the O of the air. Their characteristic chemical constituent is iron. They are supposed to be developed from white corpuscles, and modified to take part in respiration, as carriers of O. They are continually reproduced and destroyed.

Blood, drawn and left to itself, partly turns solid, or *coagulates*. This depends on *fibrin*, an albuminous substance which is liquid in circulating blood. In coagulating, it entangles most of the red corpuscles. Blood may coagulate within the blood-vessels, obstructing them.

The part of blood that remains after separation of the corpuscles and fibrin is called serum. It contains albumen, and coagulates on boiling.

Liquor Sanguinis { Serum / Fibrin } Coagulum.
Corpuscles }

Blood is alkaline, contains a little fat. Its sp. gr. is about 1,055; its temperature in life is about 100° F. Its quantity is estimated at from $\frac{1}{5}$ to $\frac{1}{13}$ of the body-weight.

Blood serves as a medium of exchange between the several tissues. It brings nutritious material to them, and carries off the results of their waste. It therefore differs in composition and characters in different parts. The most obvious of these variations is that between bright, florid blood, as it comes from the lungs, containing an extra portion of O, and the darker blood coming from its circuit over the body, with an extra portion of CO_2, derived from the wasting tissues.

In describing the **Circulation** of the **Blood**, we must consider, (1), the organs; (2), the course; (3), the moving powers of the circulation.

1. Organs are Heart, Arteries, Capillaries, Veins. The *heart* is the central pumping-engine; *arteries* are tubes that branch off from it; *capillaries* are minute

passages between extreme arteries and veins; *veins* are tubes that converge and bring blood back to the heart.

The *Heart* may be described as an inverted cone, with its apex downward and to the left. Its upper line is nearly at the level of the second intercostal space; its apex beats between the fifth and sixth ribs. It is about 5 inches long, and 3½ wide, in the adult; and weighs about ten ounces. It grows larger till old age. It is mostly overlapped by the lungs.

It is a double organ; its two sides may be called the right and the left heart. Each side consists of an Auricle, or receiving-chamber, and a Ventricle, or discharging-chamber. The two auricles are at the upper part, separated by a wall common to the two. The ventricles are at the lower part, also divided by a common wall.

The walls are red, striated muscle, lined by one serous membrane (endo-cardium), and covered by another (pericardium). This last is reflected and strengthened by fibrous tissue, to form the heart-sac. These membranes obviate friction. The ventricles are much thicker than the auricles; the left ventricle is two or three times as thick as the right.

Between each ventricle and auricle are valves, with angular membranous flaps governed by firm cords springing from the walls of the ventricle (auriculo-ventricular,—mitral and tricuspid). At the openings of the great arteries from the ventricles are smaller, pocket-like, semi-lunar valves, which flatten when blood passes out, then immediately close the orifice (aortic and pulmonary).

Arteries. The pulmonary artery rises from right ventricle, and passes to the lungs. The aorta rises from left ventricle, and its branches form a system of branching

tubes, extending all over the body. They present three principal coats; the inner, smooth and resembling serous membranes; the middle, composed of elastic tissue and circular muscular fibres (not striated); the outer, a sheath of condensed connective tissue. In the middle coat, elastic tissue predominates in the large arteries; muscular, in the small.

The *Capillaries* are minute tubes, differently arranged in different textures. They have one coat, continuous with the inner arterial lining. They communicate together very freely. Their aggregate sectional area is vastly greater than that of the arteries.

Veins have the same coats as arteries, but less firm and elastic, so that they flatten after death. They communicate more freely than the arteries. The external veins have valves, which prevent reflux away from the heart. The united sectional area of the great veins is nearly double that of the aorta.

2. Course of the Circulation.

There are two complete circuits. The *larger* circuit carries blood all over the body, for purposes of *nutrition;* the *smaller* circuit carries it through the lungs, for purposes of *respiration.*

Blood, returning by the veins from its larger circuit over the body, enters the right auricle, which immediately transmits it to the right ventricle; this contracts and pours it into the pulmonary artery which branches through the lungs. Here, it is changed by the air, its color turning from purple to florid red. It then passes by the pulmonary veins to the left auricle, thence to left ventricle, which contracts and drives it powerfully into the great Aorta, of which the arteries of the larger

circuit are branches. The blood passes through these arteries, reaching every vascular part, then traverses the capillaries and enters the veins. These converge from all distant parts into two main venous trunks,—*vena cava ascendens* and *descendens*,—which enter the right auricle. Thus, the double circuit, or figure of 8, is completed.

Blood is *florid* in pulmonary veins, left heart, and arteries of the larger circuit; *purple* in veins of the larger circuit, right heart, and pulmonary arteries.

But the larger circuit is not so simple as hitherto described. Blood to nourish the heart itself leaves the Aorta by special arteries, rising close to the valves at its opening; they are called *coronary*. It is brought back by the coronary veins direct to the right auricle. This is the shortest course from left to right heart.

The veins from the stomach, intestines, &c., converge into a single trunk, *vena portæ*, which branches again through the liver. So the blood in these veins traverses two sets of capillaries; first, those in the stomach, &c.; secondly, those of the liver. The veins from the liver bring it to the hepatic veins, which pour it into vena cava ascendens. This is a long and complicated journey from left to right heart.

3. The great *Moving Power* of the Circulation is the muscular contraction of the ventricles. During this contraction the auriculo-ventricular valves are closed, being securely tightened by the muscular columns at the base of their cords. The blood is therefore poured out into the great arteries.

The two ventricles contract at the same instant; so do the two auricles. After the ventricles have contracted, there is a pause; then the auricles contract, and instantly after them the ventricles. This double series

of acts takes place, usually, oftener than once a second, through our whole lives.

The heart during contraction of the ventricles lengthens a little, and its apex is thrown forward and rotated from left to right. This depends on the spiral arrangement of the fibres of the ventricles; it produces the *beat* of the heart.

The heart's action produces two sounds: 1st, longer and dull; 2d, short and sharper, followed by a pause. The first depends on muscular contraction and closure of auriculo-ventricular valves; it marks the instant of ventricular contraction; the second is caused by quick closure of semi-lunar valves.

Arterial Circulation.

With every contraction of the ventricles, a new portion of blood is thrown into the arteries, and a wave of distension runs instantaneously along them. This wave of distension is the *pulse*. It becomes less marked in the smaller branches, since the elastic reaction of the arterial walls, prolonged by capillary resistance, acts during the intervals between the heart's beats. So the intermittent flow becomes continuous by the time it reaches the capillaries.

The pulse may be felt wherever a good-sized artery comes near the skin; best where it lies on a bone beneath. (Radial, temporal, carotid, &c.) It is almost simultaneous in all arteries. Its frequency is, normally, that of the heart's action. In an adult male, it averages about 72 in the minute, varying in individuals. In early childhood, it averages over 100. It is quickened by muscular effort, exciting emotions, and during digestion; is slowest after a night's sleep.

Beside variations in rate, the pulse may be full, strong,

hard, equal, regular,—or the opposite. It may be made to record its own characters, mechanically.

The velocity of blood differs in different arteries, being greatest near the heart. In the large arteries of the horse and dog, it is about one foot in a second, increasing after each heart-beat.

Capillary Circulation.

This is the most important of all, since the nutritive and respiratory changes in blood take place here, and the whole object of circulation is to supply the capillaries with a steady and adequate flow. It can moreover be made visible.

The capillaries are elastic, not otherwise contractile. Pressure from the arteries impels the blood through them in a continuous flow, at a very variable rate.

The aggregate sectional area of the capillaries is very large. So, the blood is diffused over a vast space, and moves through them at a comparatively slow rate, giving the best opportunity for nutritive and other changes.

Venous Circulation.

In the veins, blood is propelled by pressure derived from the heart. Resistance to this force lessens by diminished friction in veins, and by the flow through the right heart clearing the way. The action of muscular pressure, with the valves in the veins preventing reflux, aids to force the blood toward the heart. The veins communicate very freely, so that if one is obstructed, collateral channels keep up the circulation. Motion in the veins is less rapid than in the arteries.

Excessive muscular exertion throws the blood with violence into the right heart; may distend it beyond its power of recovering itself; may even cause rupture of it.

Repeated often, it may cause permanent dilatation. As both ventricles contract together, the quickened efforts of the right ventricle hurry the left. Their walls may be permanently thickened, from overgrowth. Excessive action of the heart may lead to dilatation of the arteries. Emotional and mental strain may derange its action.

Bleeding from a wounded artery is more dangerous than from a vein, on account of the greater force and velocity of its flow. In a wound, not involving the lungs, bleeding is known to be arterial, by its florid color, and its powerful and intermittent flow.

The natural provisions for stopping it are these:

1. The artery *re*tracts by its elasticity, burying its end in the spongy connective tissue. A half-divided artery may be more dangerous than one fully divided.

2. Its mouth *con*tracts, its walls tending to turn inward.

3. A clot may form, plugging the vessel.

4. Profuse bleeding causes faintness, lessening the heart's propelling power.

Art may aid: 1. By position, by having the wounded part raised and supported. 2. By pressure, on the wound, or on the artery between it and the heart. In bleeding from a vein, pressure should rather be beyond the wound. 3. By cold and other astringent applications. 4. By tying the artery. This may be done at the wound, or on the artery above.

History of the Doctrine of the Circulation.

The ancients believed the veins to be the true blood-vessels, and the blood to move forward and backward in them, like a tide. They were thought to originate from the liver, in which the blood was concocted. The arteries, which are commonly found empty and open after

death, were supposed to convey air, to cool the blood. Florid blood was called *spirituous*; the dark, *fuliginous*, or sooty.

Galen, physician and anatomist, (A. D. 131—200,) proved that the arteries contain blood. He believed it to be impelled by the movements of respiration. To explain the passage of blood from one side of the heart to the other, he believed that part goes through the lungs, but part by minute openings in the party-wall between the two ventricles.

On the revival of independent study of nature, modern anatomists looked in vain for these openings, and sought other means of explaining communication between right and left heart. Vesalius (1512—1564) was one of the first to contradict the authority of Galen.

Servetus (1553) first described the pulmonary circulation.

Cæsalpinus, Ruini, and others, (1569—1599,) stated the facts of the general circulation in terms which seem to imply that they understood the main truth. But they did not support it by experimental evidence, and left it an unproved hypothesis.

William Harvey, born in England, 1578, student at Padua, 1598—1602, there saw the valves in the veins carefully exhibited. He perceived that they would permit these veins to carry blood *toward* the heart only. Starting from this, he conceived the idea of the double circuit. After many observations, he taught it in his lectures at London, 1616; and published a small treatise in 1628. His work is a model of inductive reasoning. He proved that the heart is the great moving power of the circulation, that blood goes out from it by the arteries and returns by the veins, and that its passage from right to left heart is by the pulmonary vessels. Among

his sources of proof, were the "curious and cunning formation of the valves and other structures of the heart,"—the different effects of pressure on arteries and veins,—the size of pulmonary artery, too large to be used merely to nourish the lungs,—the amount and rapid current of the blood. He described very accurately the heart's motions. His doctrine excited great controversies, but was generally adopted before he died, in 1657.

In 1661, Malpighi first saw the capillaries, and so completed the cycle of this great discovery.

4. Respiration.

The object of breathing is to discharge from the blood a portion of CO_2, and take in O. Its seat is the *Lungs*. The *trachea* brings air to the lungs. This extends from larynx into the thorax, and divides into right and left *bronchi*, which branch through the two lungs. Its walls consist of white bands of cartilage, deficient behind, with elastic and muscular tissue between the bands, and a lining of mucous membrane. In the small bronchial tubes, the white bands dwindle and become irregular. The tubes end in clusters of air-cells, with very thin walls. Each cluster grows on a separate twig, and so the lung is divided into lobules.

The pulmonary capillaries lie on the walls of the air-cells; and here the dark blood is separated from air only by a very thin, moist membrane, which gases can pass freely through, and this over a very extensive surface, on account of the minute branching of the air-tubes. In cold-blooded animals, the tubes are much less subdivided, cells few and large, respiratory surface is less. Each lobule of the human lung may be compared to a frog's lung.

The lungs are two conical organs reaching from neck to diaphragm. Each lies in its separate cavity, lined by serous membrane, the *pleura*. The lung-substance is made up of bronchi and air-cells, pulmonary blood-vessels, and connective tissue. It is light, spongy, floats in water and crackles on pressure, on account of the air in it.

The respiratory act is repeated about seventeen times a minute in a healthy adult, oftener in children, or after exertion or excitement. Even the attention required to count it, often quickens it. During inspiration a soft, breezy murmur marks the passage of air toward the air-cells.

Only a small part of the air in the air-passages passes in and out at each breath: (perhaps 25 or 30 cubic inches, while more than 200 c. i. can be expelled by a forced expiration.) Vital capacity, tested by spirometer, increases with height, is impaired in many diseases. The respiratory movements alone would only renew the air in the larger tubes. That remaining in the smaller branches, by the law of diffusion of gases, tends to exchange contents with the fresher air above. It thus parts with its excess of CO_2, and receives a portion of O. This diffusion is aided by the warmth of air in the lungs.

Changes produced in air by breathing:

1. Air is warmed, to 99° F.
2. CO_2 is increased to perhaps 4 parts in a 1000 (by volume).
3. O is lessened.
4. Watery vapor is increased.
5. Some animal matter is thrown into the air.

The second and fifth are the most injurious changes. The last may simply load the air with warm and moist organic matter, tending to putrefy, or may introduce the

germs of specific diseases. If air be not renewed, CO_2 accumulates; discomfort is produced in most persons by air containing 3 in 1000 vols. Breathing air excessively charged with products of respiration is speedily fatal. Insufficient ventilation, long continued, lowers the strength, makes persons more liable to disease from taking cold; and increases tendency to tubercular disease.

Combustion and artificial lighting tend also to exhaust O and increase CO_2 in air.

Impurities of air may be gaseous, or solid matters in suspension. The first include the results of respiration and combustion, and gases from decomposition and bad drainage. Suspended matters may be merely irritating, or poisonous. To the former belong particles of metals, coal, cotton, &c. Iron dust is extremely irritating to the lungs. Poisonous suspended matters are the germs of diseases.

Natural agents for purifying air: 1. The diffusion of gases; they rapidly penetrate one another. 2. Currents of air and winds. 3. The vegetable kingdom.

Artificial ventilation generally depends on the rarefaction of heated air, which tends to rise; *e. g.*, chimney and open fire-place.

5. Assimilation.

Some portions of the blood, not normally including its red corpuscles, exude from the capillaries, and furnish the material for renewal and growth of the several textures. The nature of the process by which these textures select their appropriate material and assimilate it to their own structure, is not understood. The agents of this assimilation are the component cells, or the protoplasm composing them.

Among the conditions necessary to healthy assimilation are these: a regular and near supply of blood; a normal composition and state of the blood; a healthy state of the part to be nourished, and a certain influence of the nervous system.

6. Secretion.

Some elements drawn from the blood, instead of nourishing the organs, are thrown off from the skin or mucous membranes, in liquid form. These liquids are called *secretions;* and the process is called *secretion.*

The uses of secretion are:

1. To free the blood from substances produced in the chemical processes of life, which might become noxious. Carbon compounds are thrown off by the lungs and skin; so that respiration is akin to secretion. Nitrogenous compounds, also phosphates and sulphates, are discharged by the kidneys. Many secretions cannot be checked without danger to life. Compare suspended breathing with suspended action of the kidneys.

2. To carry off alien substances that have entered the blood accidentally, or in excess,—as poisons, or excessive products of digestion. Kidneys are the great agents in this.

3. To remove superfluous water from the blood. Kidneys and skin are the chief agents; the first in cold, the second in hot weather.

4. Some secretions have some further use in the system; *e. g.*, gastric fluid. The name excretion is applied to secreted liquids which pass off without serving any farther useful purpose,—as urine.

Secretion may take place in mere shallow depressions of mucous membrane; or, in passages enormously elongated by branching or folding. Special secreting organs

are called glands, and the outlets for discharge of the liquids are ducts. Glands are composed of these branching ducts, of blood-vessels bringing blood to furnish material for secretion, and of cells in which the secreting power immediately resides.

The *liver* is the largest gland, weighing nearly four pounds. It lies just beneath the diaphragm, on the right side. It is composed of little lobules; each contains the elements of the entire gland, and is a miniature liver. The liver, beside secreting bile, forms sugar, which passes into the veins and disappears in the lungs.

The *kidneys* lie on each side of the spine, behind the abdominal cavity. Each consists of two portions,—the outside, which secretes urine; the inner, which collects the urine, and conducts it to the outlet. This inner portion contains ducts that converge into pyramidal projections in the central cavity of the kidney. From this cavity, lying in the notch of the kidney, passes a duct, named ureter. The two ureters enter the bladder, and from this passes the urethra; so that ureters, bladder and urethra form, all together, the ducts of the two kidneys.

The Skin as an Organ of Secretion.

The skin contains two structures,—*derma*, or true skin, and *epidermis*, or cuticle. The *derma* is the thicker, and consists of a network of fibres, closely united to the connective tissue beneath it, in which lie the blood-vessels and nerves of the skin. This, when tanned, makes leather. Over this vascular and sensitive covering of the body lies the *epidermis*, receiving no blood, insensible, and composed of flattened cells, which are formed on the surface of the true skin, and constantly grow dry, and wear off. The deeper cells are softest

and roundest, and contain the coloring matter; more abundant in some parts, and in some races. The epidermis shields the tender derma, and keeps it moist, by checking evaporation.

Two fluids are poured out on the skin. One is oily, and is formed in special organs commonly found near the roots of the hairs. The other is watery, the sweat. This is separated from the blood in folded tubes, lying deep in the derma, and is poured out through ducts that penetrate the cuticle. These are found in almost all parts of the skin.

The ingredients of sweat, beside water, are principally mineral salts, especially sodium chloride; and with it, derived from the mixture of the oily secretion, are fatty acids which have odors characteristic of different regions and different races of animals. Sweat also contains a little CO_2. It is usually acid. Its quantity is great, on account of the extent of the tubes in which it is formed. More substance usually passes off by the skin than the lungs. It is increased in hot weather, also by taking much drink and much exercise, and sometimes by emotion. It is more abundant when the kidneys act little. The secretion of the skin is controlled by the condition of the blood-vessels beneath it. When these are contracted, as by external cold, less sweat is poured out, and hence less heat is lost by evaporation from the skin. When they are dilated, perspiration is increased, and the body more cooled off by evaporation. These vessels of the skin are partly controlled by nervous influence, as shown in the effects of emotion.

In the frog, the skin is an important organ of respiration. In man, the epidermis interferes with respiration by the skin. Complete obstruction of the pores causes death; probably by blood poisoning.

7. Animal Heat.

Mammalia and birds preserve nearly a uniform warmth under all changes of external temperature. A thermometer with its bulb in the armpit of a healthy man shows a temperature of about 98.4° F. This is lowered a little in the night, or by exposure to cold without exercise, or by alcoholic drinks,—increased by active exercise if not exhausting. After a full meal, it is first lowered, then increased as digestion advances. It is very little higher in tropical than temperate climates.

Reptiles, frogs and fishes have much less animal heat, and are called cold-blooded. Certain mammalia hibernate, or remain through winter torpid, and breathing little; their temperature sinks to 50° or less.

To make the temperature so nearly uniform, the production, distribution and loss of heat must be nicely regulated.

a. Animal Heat is *produced* by the chemical changes going on within the body, especially those which accompany muscular exercise, nutrition and secretion. In muscles it is raised one or two degrees during contraction. It is warmest in veins leaving the liver. It depends mainly on oxidation within the body, yet is not in exact ratio to the O taken in, or the CO_2 and other oxides thrown off.

Production of heat is increased under exposure to cold, if not excessive. Hence the glow of reaction after a cold bath, or in bracing air. This is greatly promoted by muscular activity and adequate food.

b. Animal Heat, produced very unequally in different organs, is *distributed* and *equalized* by the blood rapidly flowing from part to part.

c. The principal *loss* of animal heat is through the skin, by radiation, conduction and evaporation of sweat, particularly the latter. Probably more than three-quarters of the loss is through the skin. Some is spent in warming the air and watery vapor thrown off in expiration.

III. The Nervous System, and its Functions.

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1. Its **general uses** are:

a. To associate the functions of different organs, so that they may act in harmony.

b. To establish a relation between body and mind, enabling us to perceive sensations, and to produce voluntary movements.

For these purposes, a special force is developed, found only in animal races, and known only by its effects. It is called nervous force. It is probably evolved, like muscular force, from the oxidation of elements of the tissues or the food. It has a definite rate of transmission, much slower than that of electricity.

The organs specially set apart to evolve this force are called nervous-centres, or ganglia. They contain a gray, drab, or pink substance, consisting of microscopic cells and filaments, known as the *gray* nerve-tissue. The organs specially set apart for transmission, or to communicate between one organ and another, are composed of filaments united into bundles, and form the *white* nerve-tissue. A nerve consists of bundles of filaments, bound together by a white, firm sheath, and communicating between a nerve-centre and a muscle or organ of

sensation. An *afferent* nerve is one carrying messages toward a nerve-centre; an *efferent* nerve conveys impressions from a nerve-centre. A *commissure* is a collection of filaments communicating between one nervous centre and another.

Nervous filaments when fully developed consist of a tubular sheath, containing a fatty substance, and within this a thread (axis-cylinder), of albuminoid composition. The bundles may branch, or interchange filaments, indefinitely; but each filament is believed to be distinct and continuous from end to end.

The gray nerve-tissue, as it contains filaments as well as cells, may transmit messages; and the white nerve-tissue may, in some instances, evolve force, even when isolated from a nerve-centre.

The analogy of nerve-centres to the batteries of the magnetic telegraph, and of nerves to the wires, is obvious, but imperfect and misleading.

Chemically, nervous substance contains albuminous and fatty matters, with mineral compounds, especially phosphates.

2. Spinal Cord and Medulla Oblongata.

The chief nervous centres of Vertebrata form a continuous mass, contained in the spinal column and cranium,—the cerebro-spinal axis. The part within the cranium is often called *encephalon*, or brain. That within the spine is the *spinal* cord.

The spinal cord extends from foramen magnum of occiput to below the first lumbar vertebra, where it divides into separate nervous threads. It is cylindrical, divided into right and left halves by deep fissures in front and behind. It contains gray substance inside, and white outside. The *gray* substance forms a contin-

uous column through each half of the cylinder, the two columns being connected by a cross-band. A section across it shows a double crescent, with the cross-band uniting the convexities of the two crescents. This gray substance may be viewed as a series of ganglia blended into a long double column. The *white* substance in each half lies in three columns or tracts,—anterior, lateral and posterior. The cord is surrounded by connective tissue and fat, by three membranes, and a layer of liquid which keeps up gentle pressure and yields to all movements.

The cord sends out nerves between the vertebræ. These begin by two bundles of filaments,—the anterior and posterior roots,—which unite before leaving the spine. The posterior root passes through a ganglion. There are thirty-one pairs of spinal nerves.

The cord entering the cranium dilates into a wider oblong body,—*Medulla oblongata*,—anatomically a part of the encephalon; physiologically, of the spinal cord. This lies on the smooth surface in front of foramen magnum,—a very safe place. The columns of gray substance here separate, and are no longer continuous and uniform. Distinct gray ganglionic masses are formed, with specific functions. The anterior columns of white substance cross at the lower part of Medulla oblongata,—the "decussation of the pyramids." This crossing is often incomplete.

The spinal cord has a two-fold function:

1. It makes a communication between the brain and all those parts that get their nervous supply through the spinal nerves.

2. It is also a distinct nervous centre, the seat of intrinsic power.

1. The brain, being the organ of perception and will, must have a nervous communication with the organs of sense, and with the muscles that are to be moved. Otherwise, the mind cannot perceive the sensations, nor the will act on the muscles. Hence, if the cord be cut, or eaten through, or in any way disabled, parts supplied by nerves which leave the cord below that point are paralyzed, or made incapable of sensation and voluntary movement.

The gravity of such an injury depends mainly on its situation. At the top of the spine, it is promptly fatal.

The anterior roots of spinal nerves are *motor*, or efferent. The posterior are *sensitive*, or afferent. Stimulating the anterior root causes spasmodic movements; dividing it paralyzes movement. The anterior and lateral columns of the white substance of the cord are mainly motor tracts; the posterior columns mainly sensitive.

Disease or injury of the brain usually disables the opposite side, if any part, of the body. This is on account of the decussation of the pyramids.

2. The Cord is also a ganglionic organ,—a seat of intrinsic power. It is one great centre of acts called *reflex*.

Nervous centres may act in two different ways in producing movements: (1) The physical impulse may originate in the nervous centre, as when I will to lift a weight, and the impulse begins in my brain, and is conveyed thence by nerves to the proper muscles. The brain is the chief centre of these *spontaneous* acts. (2) The impulse may be made first on an afferent nerve, conveyed to a nerve-centre, and there elicit an efferent impulse which goes by nerves to the muscles. This conversion of afferent into efferent impulses is compared

to the reflection of light,—hence, such acts are called *reflex*. They often simulate conscious purpose and spontaneous movement.

A hen kicks after its head is cut off. A beheaded frog withdraws its leg when pinched. Destroy the spinal cord, and these movements cease. Remove all external stimuli, and they cease. Hence they are believed to depend on the cord, and probably on its gray substance, and to be reflex, not spontaneous. Such motions are more marked in inferior animals. In man, the brain commonly restrains reflex movements in the limbs. When its influence is suspended, they are more marked. Some diseases, and some poisons, increase the reflex excitability of the cord. The afferent impulse which gives rise to reflex acts may be of internal origin. In the formation of habits, acts once voluntary may become secondarily reflex. Learning to walk requires voluntary effort; at length the muscles come to move without conscious superintendence.

Medulla oblongata is a centre of reflex movements more frequent and necessary to life than those dependent on the cord within the spine. Such are swallowing and breathing. These may go on without a brain; they stop when Medulla oblongata is disabled. A bit of food touches the mucous membrane of the throat, and an impulse is sent from this membrane to Medulla; an answering impulse is sent (reflected) to the muscles of swallowing. This stage of swallowing requires no volition or consciousness; the will cannot restrain it. So in breathing, so far as it is a reflex action. The afferent impulse to excite breathing naturally starts, we may believe, from the lungs, caused by the presence of ill-oxygenated blood. It reaches a particular part of Medulla, and is thence "reflected" to the muscles of inspiration.

Chloroform, or disease of the brain, may suspend all voluntary powers, but allow respiration to go on. But not if it disable Medulla oblongata. Hence difficult swallowing is a sign of danger in such a case.

Movements of breathing could not be safely left to our voluntary control; they must continue when our minds are otherwise occupied, and during sleep. Respiratory movements are partially governed by will, especially for purposes of speech. Sneezing and coughing are modified reflex actions of the respiratory mechanism.

Voice, articulation and facial movements expressive of emotion depend in part on Medulla oblongata. It also influences the play of the heart and blood-vessels.

3. Brain.

The motor and sensitive tracts of the spinal cord are continued, above Medulla oblongata, in two thick diverging bundles of nervous filaments,—the *crura cerebri*, or peduncles of the brain. These lead to two large oval ganglia at the base of the true brain, named *basal* ganglia. The pair in front, *corpora striata*, terminate the anterior or motor tract; the pair behind, *thalami*, terminate the posterior or sensitive tract. This continuity of structure suggests the different functions of the two pairs. Corpora striata are the ganglia at top of the motor tract. When one of these is disabled, motion is lost on the opposite of the body. If both be disabled, motion is lost on both sides. The function of the thalami is not discriminated with so much certainty; their destruction has been thought to be connected with loss of common sensibility in the body. Probably they are a centre of sensation, and of some higher reflex actions.

In this lower region of the brain, are also ganglia connected with the special senses, being stations where

messages are received from the organs of these senses, and transmitted to the true brain above. The ganglia of sight lie over crura cerebri, behind thalami; they appear like two pairs. Those of smell lie on ethmoid bone. Those of hearing and taste are blended with Medulla oblongata. These ganglia of sense are not the seats where conscious perception is produced; but are intermediate between the external sense-organs and the true brain.

Now, all these nervous masses,—the subordinate ganglia of the brain,—are allied in function. They are the centres for actions intermediate between the reflex powers of the spinal cord, and truly conscious and voluntary faculties. These may involve some obscure consciousness, but not distinct perception. The maintenance of equilibrium in standing or walking depends on impressions received through the organs of feeling, sight and the ear, of which we are but dimly conscious. Emotional and instinctive acts,—many motions performed from force of habit,—mechanically, as we say,—and protective motions, by which our limbs are instantaneously withdrawn from injury,—all are believed to depend on these subordinate ganglia.

These lower ganglia of the brain are grouped together under the name *sensori-motor;* and actions of this class are called *consensual.*

The *Cerebellum* lies in the hollow of the occiput. Here we first find the gray substance outside of the white, its surface folded in parallel furrows. The white is so arranged that a section of it resembles a branching fern. It is connected by commissures with other parts of the brain. The special commissure between the two sides of the cerebellum passes like a bridge over the ascending tracts of Medulla oblongata and crura cerebri,—and this part of the brain hence takes the name of *pons Varolii.*

The cerebellum is specially connected with the powers of movement. It appears to be a centre through which motor impulses are made to harmonize so as to produce a desired result. It is large in many species of animals remarkable for varied and rapid movements. After its removal, birds have been found to perform strange, irregular, sprawling movements. Its diseases often make locomotion unsteady.

Cerebrum, or True Brain.

From the level of the basal ganglia, the nervous tracts spread outward into two great masses,—white in their interior,—the right and left hemispheres of the Cerebrum. In these, a large amount of gray nerve-tissue crowns the termination of these diverging fibres, and forms a new and most important seat of nervous energy, connected with the higher faculties of man. Above the basal ganglia, a bridge or commissure connects the two hemispheres,—the great transverse commissure.

Cerebrum fills most of the cranium, from forehead to occiput. Above, it is shaped somewhat like a flattened egg, divided by a deep fissure. The gray substance on its outside lies in folded ridges, called convolutions. These increase the extent of gray matter. They vary in individuals, and are seldom quite symmetrical on the two sides; yet they are uniform enough to have received separate names. Much gray substance does not appear on the external surface of cerebrum.

The white interior of cerebrum contains some filaments derived from ganglia below, some which run across to make the great transverse commissure, and some which unite different convolutions of the same hemisphere.

The basal ganglia lie beneath the central part of the cerebrum, projecting into cavities called ventricles, left

by the separation of the diverging columns which pass up to form the cerebrum, and roofed over by the great development of the cerebrum.

The brain, like the spinal cord, is surrounded by three membranes and a layer of liquid. It receives a very large supply of blood, through four great arteries.

The **functions** of the Cerebrum are:

1. To furnish the physical conditions necessary for the perception and retention of impressions brought from the various sensitive organs. The substance of the cerebrum is not itself sensitive.

2. To direct voluntary movements, and control other motions.

3. To supply the material conditions of thought and of all mental activity.

The **proofs** of these functions are drawn from three sources,—disease or injury, experiment, and comparison.

1. *Injury* or *disease* of the gray substance of the hemispheres impairs the powers of mind. This statement is modified by certain circumstances. Thus, a *sudden* pressure on the brain, or failure in its supply of blood, stops all powers of perception and will. Pressure may be from depressed fracture of cranium, or bleeding within the skull. The supply of blood may be lessened by loss of blood from a wound, or by obstruction of an artery of the brain. *Gradual* pressure, as by a slow-growing tumor, will have less effect. Again, the part of the cerebrum involved will influence the result. Disease of its upper part is more sure to affect the intellect; at the base of the brain, it involves rather the powers of sensation and movement; while if it disable Medulla

oblongata, it becomes fatal. But, as the brain is in an unyielding bony case, pressure soon affects all parts.

2. *Experiment.* In birds, the cerebrum has been removed, and the creatures, by care and feeding, have been kept alive long enough for their mental condition to be tested. It is one of total obliviousness, with incapacity of voluntary movement. Loud sounds and bright lights are noticed for the moment, and excite motions, but are not remembered. The state resembles deep sleep.

3. *Comparison*, between the races of men, between individuals, and animal species. There is a general relation between the amount of gray cerebral substance and mental power. In idiots, cerebrum is the part most defective. The convolutions are less developed in idiots, and in the lower races of mankind. The average weight of the brain is greater in European races than in the Mongolian, and least in Australians, among all human races where it has been observed.

In Man, the cerebrum predominates over those parts of the brain especially connected with mere instinct, sensation and mechanical powers. This fact obscures the relation between the parts of the brain, which is made clearer by comparative anatomy.

The fish's brain presents a row of similar ganglia,—one pair connected with smell, one with sight, one that represents the cerebrum, and a cerebellum. Beneath these are others that probably correspond to the basal ganglia. The brain is not very much larger across than the spinal cord.

As we follow the ascending scale from fish to man, the cerebrum becomes larger in proportion, till it overlaps and hides the other ganglia. In reptiles, it does not cover over the centres of sight and smell; in birds,

it partially does so. In most Mammalia, looking from above, we see something of the olfactory ganglia, cerebrum and cerebellum. Convolutions are either wanting or very slightly marked in birds and the lower Mammalia; so is the great transverse commissure of the cerebrum. In Man alone, the cerebrum overlaps all the other ganglia of the encephalon.

Localization of Functions in the Cerebrum.

Different parts of the gray substance of cerebrum may have distinct powers. One local function of a particular convolution is proved by numerous cases of disease and injury, viz., the faculty of conceiving of words, and directing their articulate utterance, seated in the convolution at the lower part of the left frontal lobe. The loss of this function,—*aphasia*,—therefore occurs with paralysis of the right side.

Recent experiments appear to show still more localization of cerebral powers. These have been performed on animals whose convolutions somewhat resemble those of man, as monkeys. Different parts of the brain's surface are stimulated by a gentle electric current, producing movements or sensations more or less uniform for each region. Again, certain convolutions are destroyed, and certain powers are lost in consequence. From such experiments, it appears that the nervous centres for directing most muscular movements lie in the frontal and parietal regions, and that each group of muscles has its definite centre. The cerebral seat of visual perception is believed to be in the "angular convolution," nearly beneath the parietal protuberance. Here, it is thought, the physical impressions of light, color and form, transmitted from the eyes to the optic ganglia, produce distinct modifications of consciousness, or ideas. The centres of the other special senses are not so well defined.

4. Sympathetic System.

The sympathetic system forms a channel of mutual influence between the nutritive and the cerebro-spinal functions. Through it, mental states and emotions affect the heart and stomach; and the condition of the nutritive organs affects the mind and feelings. Its action is involuntary, and many reflex movements necessary for the processes of nutrition depend on it.

It presents:

a. Numerous ganglia and plexuses of nerves near the chief centres of the organic functions, as the heart, stomach and intestines.

b. A double chain of ganglia running down near the spine, on each side, and at the back of the trunk, communicating freely with the spinal nerves. There is usually one pair to each vertebra.

c. Some small ganglia within the head.

The heart contains ganglia within its own substance, which keep up its regular motions.

Branches, derived partly from the sympathetic, partly from cerebro-spinal nerves, accompany and control the smaller arteries, regulating the action of their muscular coats. These nerves are called *vaso-motor*. When one of them is stimulated, the vessels under its control contract and admit less blood, and the parts grow pale. When it is cut, they dilate and admit more blood. Different emotions may produce similar effects. The muscular coat of the smaller arteries is maintained in moderate contraction by nervous influence, and this may be increased or lessened as required. Thus are produced local variations in the distribution of blood.

The vaso-motor nerves influence secretion; as when the flow of saliva or gastric fluid is caused by the contact, or the desire, of food.

5. Hygiene of the Nervous System.

a. Physiological conditions of healthy and continued mental activity.

Mind is manifested only through the agency of the Brain; and the Brain is subject to the same laws of inheritance, development, nutrition, exercise and rest, as other organs. Hence mind works under physical limitations.

We may name seven conditions:

1. *Hereditary Brains.* Race and ancestral characteristics and culture are important factors. Individual traits of mind, as well as body, are inherited.

2. *Age and Development.* The brain is gradually developed, not always at the same rate, depending on stimuli and exercise. A child's brain can no more do the full work of an adult's than can his muscles.

3. *Adequate supply of Blood to the brain.* Sustained mental activity requires enough food and good digestion. Nature usually indicates, by appetite, the amount of food needed. Nerve-substance contains fats and albuminoids with phosphorus; and these must be supplied in food.

4. *Purity, or a normal composition of the Blood.* Digestion introduces imperfectly assimilated food into the blood. Hence we cannot study well after a hearty meal. Depurating processes are secretion and respiration. If these are not free, the vital flame is choked by its own ashes. Retention of urea is fatal in a few days. The non-elimination of biliary ingredients clouds the mind. Respiration must be free.

more sensitive. The use of either as a supplement to insufficient food is a great evil.

The active principle of both is nearly the same.

2. *Alcohol.* The effects of alcoholic drinks need no description. They are thus explained: alcohol weakens the action of the vaso-motor nerves, so that the smaller arteries yield to the dilating force of the heart's beat. To fill the dilated vessels, the heart has to beat more rapidly and sharply. Hence the flushed face and excited brain. They show not increased, but impaired power: "a relaxation, an absolute paralysis, of one of the most important mechanisms in the animal body, the minute, resisting, compensating circulation."* This effect may be useful in flushing the brain, as after great loss of blood.

Habitually used, they tend to produce, in the young, derangement of the digestive and nervous functions; in older persons, organic disease of the heart and arteries, the liver and kidneys, and the brain. The habit itself becomes a disease, and a source of hereditary disease.

3. *Tobacco.* The specific effects of tobacco-smoking depend on *nicotine*, a volatile alkaline poison, which is inhaled. They are most marked when the air is heavily charged with nicotine, when tobacco is used before eating, and during the growing period of life. Tobacco produces functional rather than organic disease, making the heart's action irregular, disturbing the chemistry of nutrition and secretion, altering the blood, deranging the reflex movements of stomach and intestines, and variously impairing the vigor of the nervous system.

*B. W. Richardson, M. D.

6. Sensation.

The five senses known to exist in the higher animals are touch, taste, smell, hearing, sight. Each requires a surface to take impressions of its special kind, a nerve to transmit them, and a part of the brain to receive them, and convert them into perceptions. If either of these be wanting, that sense is lost.

a. Touch. The outer surface of the derma is raised in little projections, or papillæ, which make ridges seen on the finger-tips and palms. Blood-vessels and nerves running beneath the derma send twigs to the papillæ. These are most abundant in the most sensitive parts, and in the fingers the nerve-twigs end within the papillæ in oval bodies, named tactile corpuscles. The sensibility of the skin varies greatly in different regions. The hand is peculiarly the organ of touch.

b. Taste and Smell. The senses of Taste and Smell are closely allied. Both serve for the choice of food as well as for enjoyment. Both influence digestion. Both reside in mucous membrane.

Taste resides in the tongue; most acute at its back part, tip and edges, also in the sides of the throat. The tongue, like the skin, bears papillæ. Taste, like touch, has no nerve exclusively appropriated to it.

Smell resides in the upper part of the nostrils. Odors must be in form of vapors, or minute particles soluble in the moisture of the mucous membrane. A special pair of nerves, and of nerve-centres, the olfactory, is appropriated to this sense.

c. Hearing. The Ear. The external canal of the ear, about an inch and a third long, is lined by a delicate membrane which secretes wax. The *tympanic*

membrane, firm and gray, is stretched across the bottom of this canal. Beneath this, is the *tympanic cavity*, hollowed out of the temporal bone, and supplied with air by the Eustachian tube leading from the throat. Three very minute bones extend across this cavity, forming a bent and jointed lever, attached at one end to the middle of the tympanic membrane, at the other end to the membrane covering *fenestra ovalis*, an oval window leading to the vestibule of the *labyrinth*, the essential seat of hearing. From the vestibule open, on one side, *cochlea;* and on the other, three hollow arches called *semi-circular canals.* Cochlea is shaped like a snail-shell, and contains a cavity that winds spirally around a central axis, and is divided by a winding partition. The labyrinth is lined by a membrane containing a liquid, in which float the terminal branches of the nerve of hearing. The vibrations of sound, conducted by the chain of bones, from the tympanic membrane to the oval window, throw the liquid in the labyrinth into waves. To permit these undulations, there is a counter-opening between the vestibule and tympanic cavity. Both vestibule and cochlea contain mechanisms adapted to act directly on the nerve-filaments.

The special uses of the several parts of the labyrinth are not positively known. Probably, the apparatus within the vestibule enables us to hear mere noises; the cochlea aids us to distinguish the pitch of sounds. The semi-circular canals are a source of impressions which are of great importance in maintaining the equilibrium of the body; how far they contribute to the sense of hearing, is doubtful.

d. Sight. The Eye. The eye-ball rolls in a mass of loose connective tissue and fat. A strong white coat,

sclerotica, gives it firmness and globular form, and receives the attachment of muscles that move it. In front, this coat becomes transparent and more convex, as if the segment of a smaller sphere. This part is called *cornea*. It makes about one-fifth the surface of the globe. The front of the ball is covered by mucous membrane continuous with that of the lids, and which is reflected from lids to ball a little way back. This is *conjunctiva*. It is this which feels so acutely a particle of dust.

The eye-ball contains several refracting media, which concentrate the rays of light at back of the eye. These must be transparent. They are partly liquid, partly solid. Just behind the cornea is *aqueous humor;* and next behind that is the chief refracting medium, *crystalline lens*, solid, doubly convex. In front of the lens is a colored curtain, the *iris*, with a round hole in its centre, the pupil. This cuts off all but the more central rays of light. It contains muscular fibres which alter the size of the pupil, to admit more or less light, as needed. The space behind the lens is about four-fifths of the eye-ball. It is filled with a jelly-like substance, *vitreous* humor. In this large back-chamber of the eye, sclerotic is lined by a thin, vascular membrane, colored dark by a pigment, named the *choroid* coat. This ends in front in plaited folds which turn inward and support the lens. These folds contain muscular fibres (the *ciliary* muscle) which alter the shape and position of the lens, to adapt it to near or distant vision.

The transparent media act on purely physical principles, bending the rays of light so as to reach a focus at back of the eye. This is *refraction*. The active muscular effort by which the eye is adjusted for near vision is called *accommodation*. This is chiefly performed by

the muscular fibres making the lens more convex, so that it refracts more strongly. This muscular effort is a vital act, and tends to cause fatigue, which we feel after exercising the eye on very minute objects near to.

Near-sighted persons have the media too convex, or the whole eye-ball too long. This state is increased by habitually looking at near objects with insufficient light. In the old, the lens is less elastic, and changes shape less easily.

The rays of light, brought to a focus at back of the eye, meet the sensitive surface called *retina*, the essential seat of vision. The optic nerve enters the eye-ball, penetrates sclerotic and choroid, and expands to form this membrane, concave in front. Retina contains several layers; the inmost is formed of fibres of the optic nerve; others contain nucleated cells; and next the choroid is a layer of long and slender bodies called rods and cones. This deepest part of the retina is the true seat of visual sensation. Probably the rods and cones act directly on the nucleated cells of the retina, exciting in them some unknown change which produces the sensation of light.

The optic nerve-fibres are not sensitive to light, except when stimulated through the retina. The spot where the nerve enters the eye-ball does not see.

The sight, with the sense of touch, gives us the idea of projection and solidity. To an untaught eye, all objects look flat, differing only in color and outline. This idea is also gained by comparing impressions received in the two eyes. This is illustrated by the stereoscope.

The eye is protected by many guards; the brows ward

off some injuries; the lids are curtains exquisitely quick to cover the eye when endangered; and the tears, poured out by the lachrymal gland, wash its front surface. This gland lies in the upper and outer part of the orbit. The tears are drained off by the lachrymal duct into the nostril.

Practical Suggestions.

The conjunctiva when inflamed becomes rough, and is liable to impair the transparency of the cornea. Hence, remove foreign bodies promptly, and never neglect slight inflammation there.

Eyes become congested by stooping, by any tight pressure around the neck, and by continued efforts of accommodation to near vision.

No artificial light is so favorable as daylight; it is less diffused and less steady.

Do not face a strong light. Light should come from behind, and over the shoulder. Avoid sudden changes to brilliant light.

IV. Reproduction and Development.

Reproduction, in all the higher animals, requires the union of two kinds of cells, *spermatozoa* and *ova*. The first are microscopic bodies, furnished with long vibrating cilia, which keep up active movement during life. They are contained in a liquid charged with albuminous and fatty elements. The ova consist mostly of a semi-fluid granular material, the yolk, contained in a cell-

wall, and enclosing a germinating body. The development of a new organism begins by division of the contents of the yolk-bag, till they become compacted into a new membrane, the *blastoderm*. This divides into two layers,—the outer one destined to be converted into the nervous system, integument and skeleton;—the inner, to form the apparatus of digestion and the nutritive functions. The embryo first appears as a line on the outer layer of the blastoderm, which becomes a canal representing the future spinal canal. Beneath it, the notochord is formed (page 12). The brain begins as an enlargement at the forward end of the primitive spinal cord; the eye and ear are formed by the union of growths from the brain with offshoots from the skin. The alimentary canal is developed from the inner blastodermic layer; and a protrusion from the œsophagus lengthens and branches till it forms the bronchial tubes, around which the lungs are developed.

The embryo grows, first by absorption of nutritive matter from the yolk; at a later period, by establishing a vascular connection between the ovum and the walls of the containing maternal organ. In the higher mammalia, this connection is made by a special organ, the placenta.

At birth, the lungs become active; the course of the blood undergoes changes; and nourishment, no longer supplied by direct communication with the maternal blood, must be furnished through the mouth and stomach. The skeleton is still to a great extent cartilaginous.

Development includes the whole series of changes, from the primitive form of the embryo to adult life.

Many of these changes are as wonderful, though not as open to common observation, as the transformations of insects. The nature of the force by which they are effected cannot be explained. Its normal action depends partly on inherited tendencies, so that the traits of parents and ancestors re-appear in the offspring, and partly upon surrounding influences. The hereditary constitution may be greatly modified by environment and training; inborn tendencies to disease may be fostered or obviated. Development may be arrested, so that forms normally embryonic persist.

ERRATUM.—Page 12, line 13 from bottom, *for* vertebral column, *read* vertebral skeleton.

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